NIBS 2018
The 6th International symposium on Negative Ions, Beams and Sources (NIBS'18)
3-7 September 2018
Budker INP

CONSORZIO RFX Ricerca Formazione Innovazione
Università degli Studi di Padova

Start of SPIDER operation towards ITER Neutral Beams

G. Chitarin

on behalf of NBTF team
and contributing staff of **ITER IO, F4E, INDA, QST, NIFS, IPP**
and other European institutions

UNIVERSITÀ DEGLI STUDI DI PADOVA

Outline

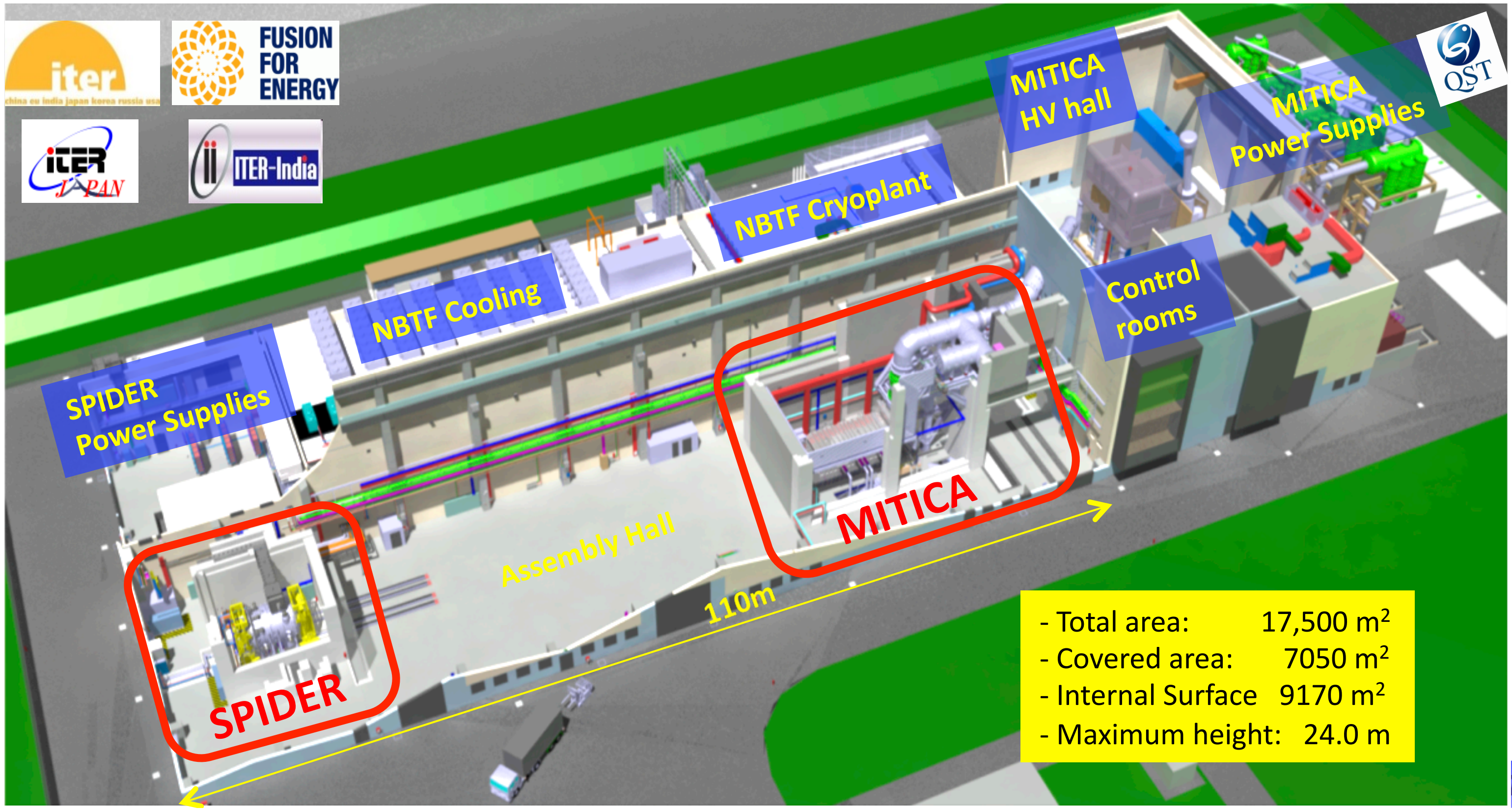
CONSORZIO RFX Ricerca Formazione Innovazione

- the Neutral Beam Test Facility (NBTF) for ITER in Padova
- SPIDER and MITICA experiments timeline
- SPIDER features and objectives
- SPIDER construction, assembly and commissioning
- SPIDER experimental plan and first experimental results

the Neutral Beam Test Facility

NBTF is essential for the smooth operation of the ion source of ITER HNB, whose design is based on concepts developed in several collaborating labs (IPP, QST, NIFS, CEA), but never tested at full performance at once in a single experiment (*).

- **SPIDER**: full-scale negative ion source and extractor having the same features and size as ITER HNB (and DNB), 46 A, 100keV. T**he experimental operation of SPIDER has started in June 2018**.
- **MITICA**: full-scale prototype of ITER HNB, 46 A, 1 MV, 5 acceleration stages, 16.5 MW, presently under construction.



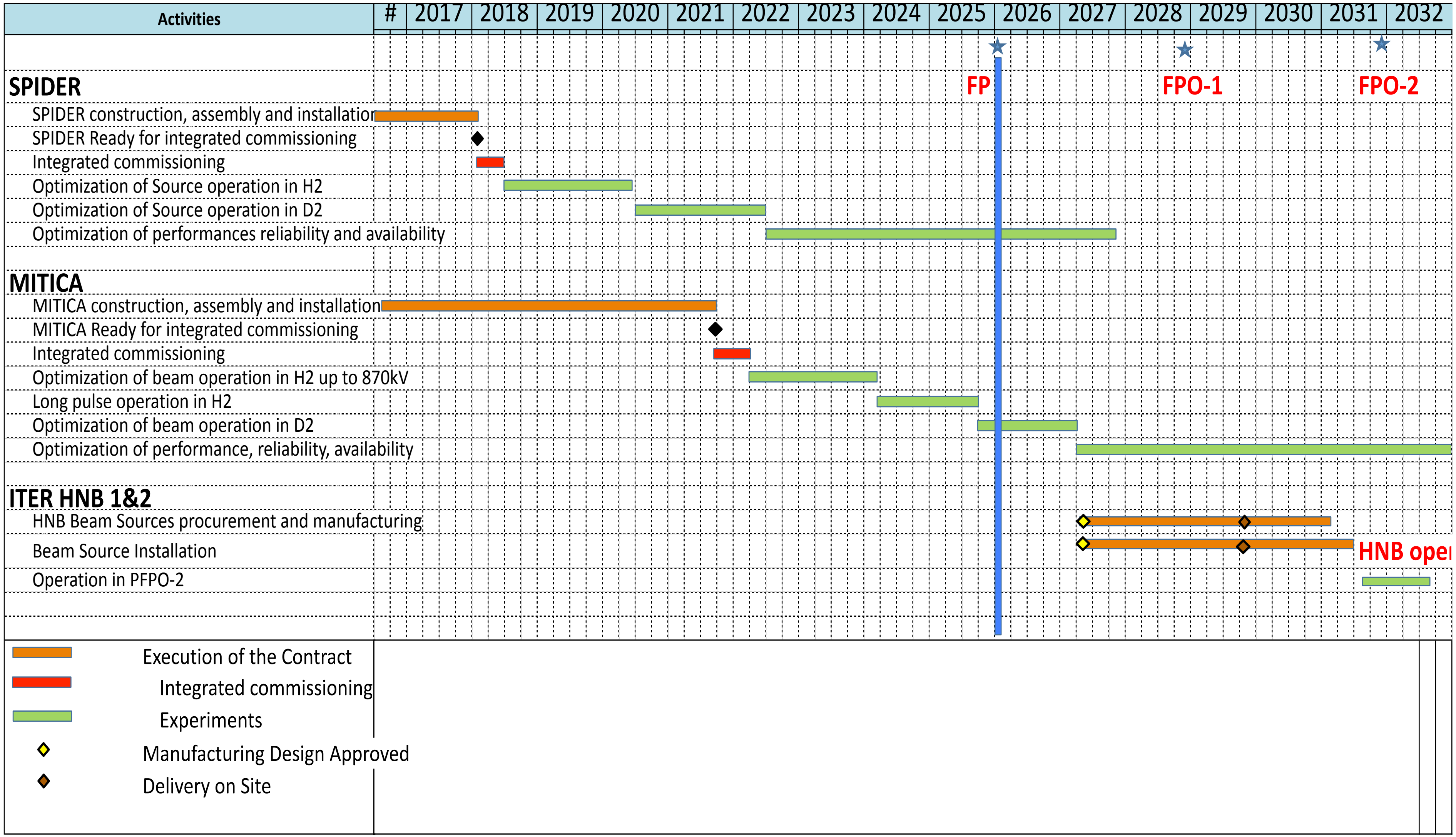
(*) see presentations :

MonO3 D. WÜNDERLICH, Long Pulse Operation at ELISE: Approaching the ITER Parameters

P1-22 M. ICHIKAWA, Demonstration of 500 keV negative ion beam accelerations for 100s toward JT-60SA N-NBI ion source

MonO5 K. TSUMORI, Caesiated H- source operation with helium

NBTF and ITER HNB timeline
(**rigid** schedule approved in 2016)



Università degli Studi di Padova

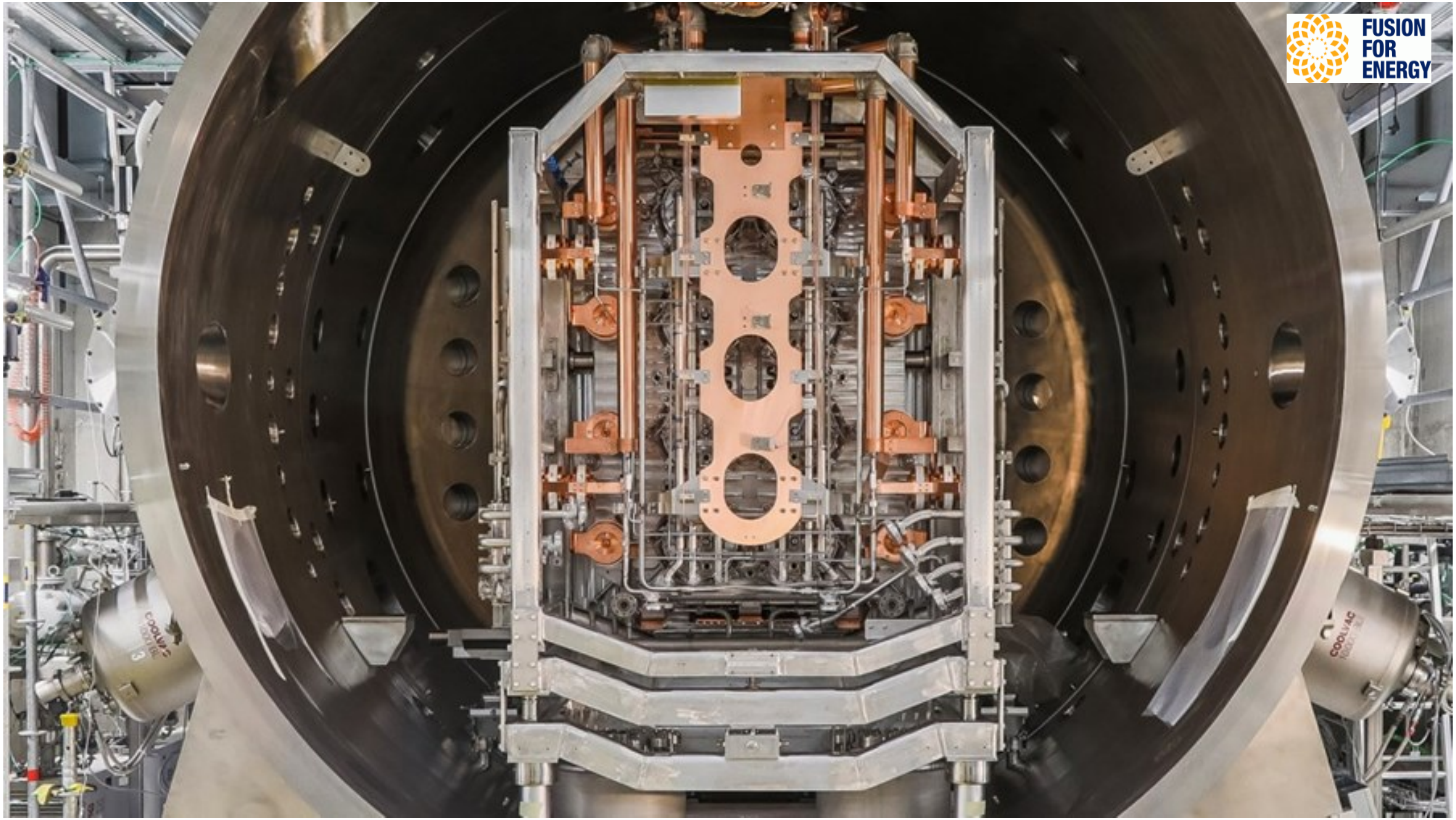
Neutral Beam Test Facility

CONSORZIO RFX
Ricerca Formazione Innovazione

UNIVERSITÀ DEGLI STUDI DI PADOVA

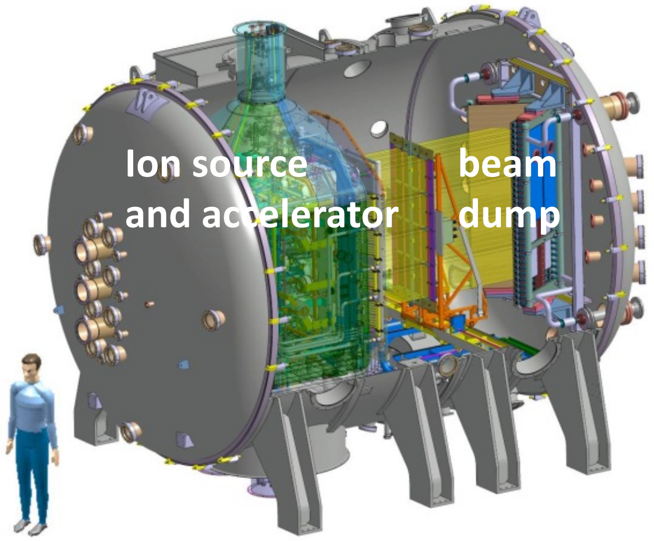
CONSORZIO RFX
Ricerca Formazione Innovazione

SPIDER: full scale prototype of HNB negative ion Source



5 m

SPIDER design and parameters



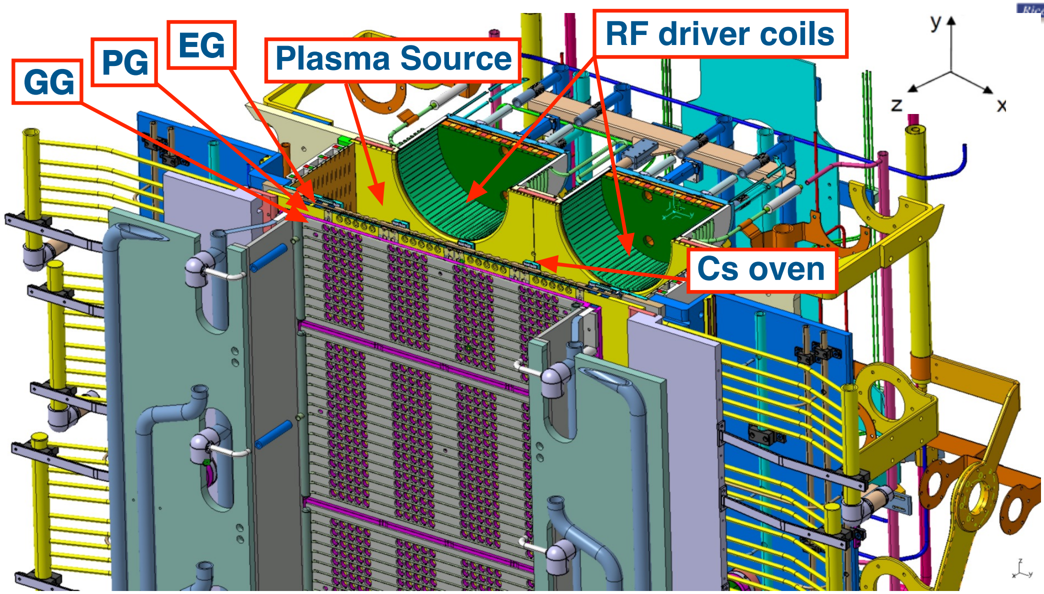
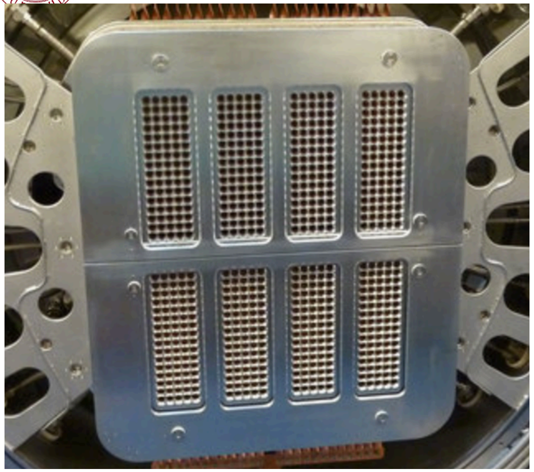


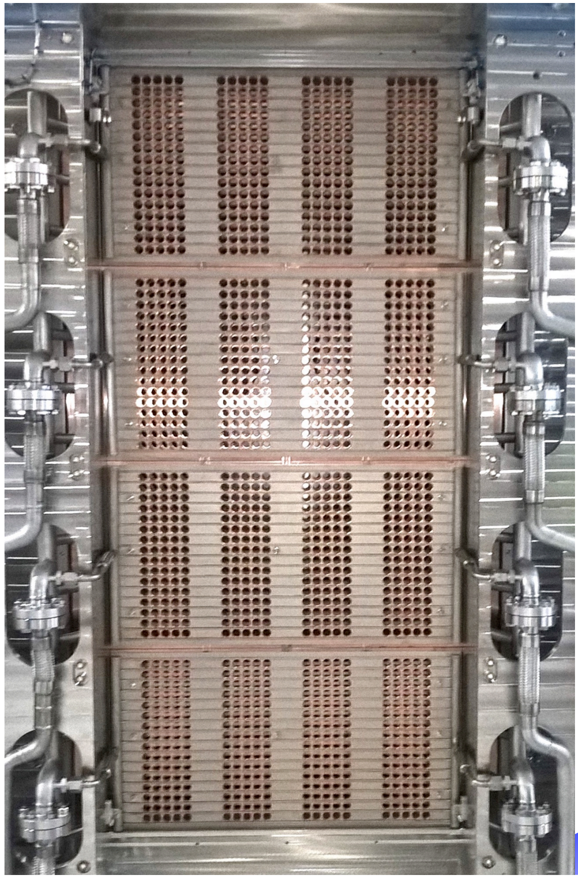
Table 1: SPIDER nominal parameters

	H^-	D^-
surface for ion production	about 1 x 2 m^2, 1280 apertures	
plasma source filling pressure	0.3 Pa	
plasma source power (8 driver coils at 1 MHz)	8 x 100 kW	
ion current density extracted from the plasma	>355 A/m^2	>285 A/m^2
co-extracted electron fraction (e^-/H^-) and (e^-/D^-)	<0.5	<1.0
max deviation of ion current density from uniformity	±10%	
accelerated ion beam current	46 A	40 A
beam acceleration energy	100 keV	
beam on time	3600s	
magnetic filter field upstream of the PG	up to 4 mT	
max heat load on accelerator grid	660 kW	
vacuum pumping speed (8 cryopumps)	8 x 12 m^3/s	

SPIDER: full scale prototype of ITER HNB ion source



ELISE
~ 0.9 m



SPIDER
~ 1.8 m

features of the ITER HNB to be achieved in SPIDER for the first time:

- **value and uniformity** of H^- and D^- current extracted from full-size **Cs-catalysed grid** in **RF-driven plasma source**, extracted **electron/ion ratio <1**
- **voltage holding** between components at different electric potentials in presence of pressure gradients produced by gas flow and during beam extraction
- **tolerance** to high **heat loads** caused by co-extracted and stripped electrons
- **acceptable grid deformation** and effects in terms of beamlet optics quality (divergence and deflection)
- **stability** of beam operation for **long pulse duration**

see presentations:

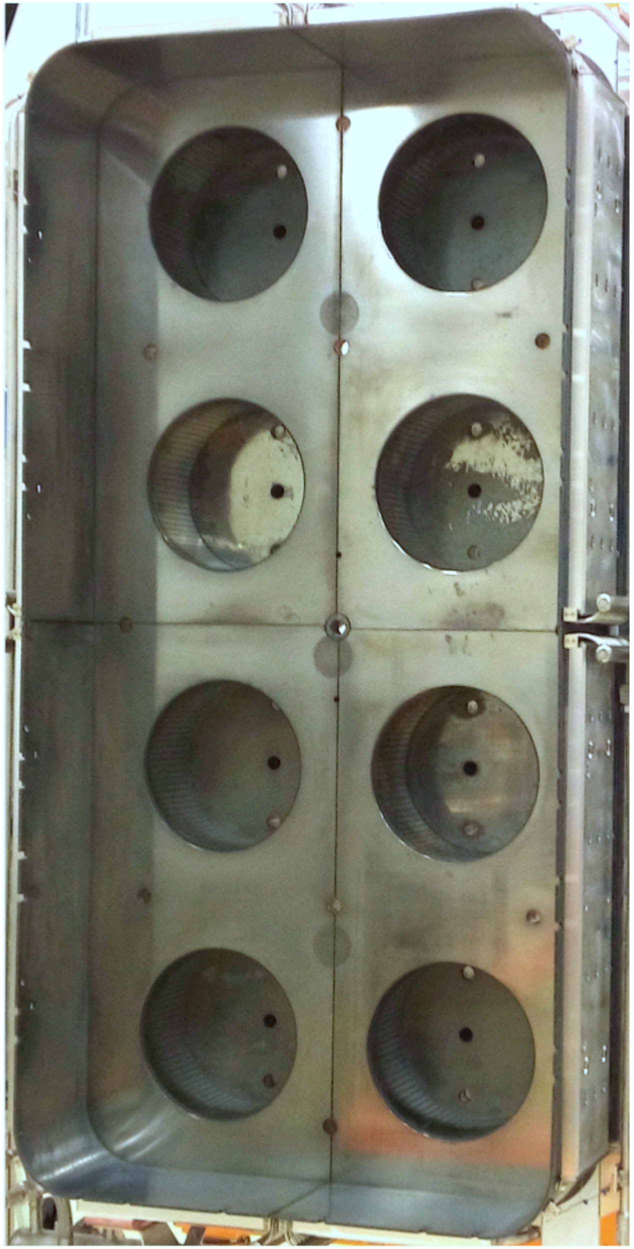
- **WedO1**, F. BONOMO, Uniformity of the Large Beam of ELISE during Cs Conditioning
- **WedO10,** A. APRILE, Complete compensation of criss-cross deflection in a negative ion accelerator by magnetic technique
- **P2-53,** T. PATTON, MITICA Intermediate Electrostatic Shield: concept design, development and first experimental tests identification
- **P1-13**, M. RECCHIA, Studies on the voltage hold off of the SPIDER driver coil at high RF power

Università degli Studi di Padova

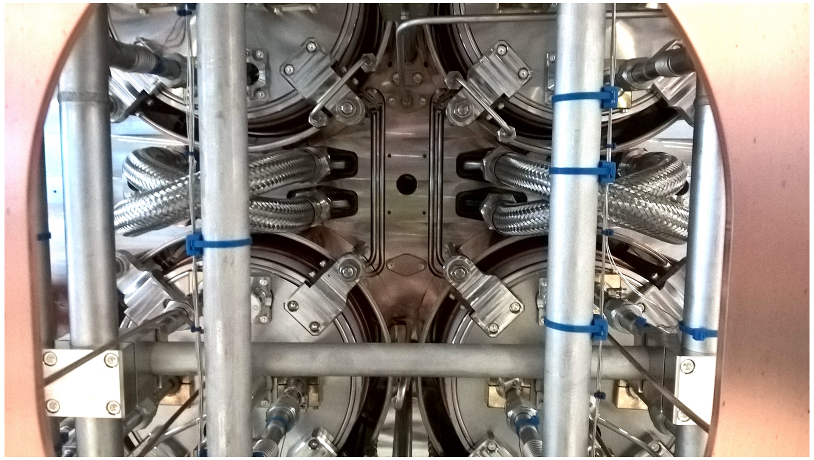
SPIDER: full scale prototype of ITER HNB source

CONSORZIO RFX
Ricerca Formazione Innovazione

Plasma Grid (PG) and Bias Plate (BP) during assembly

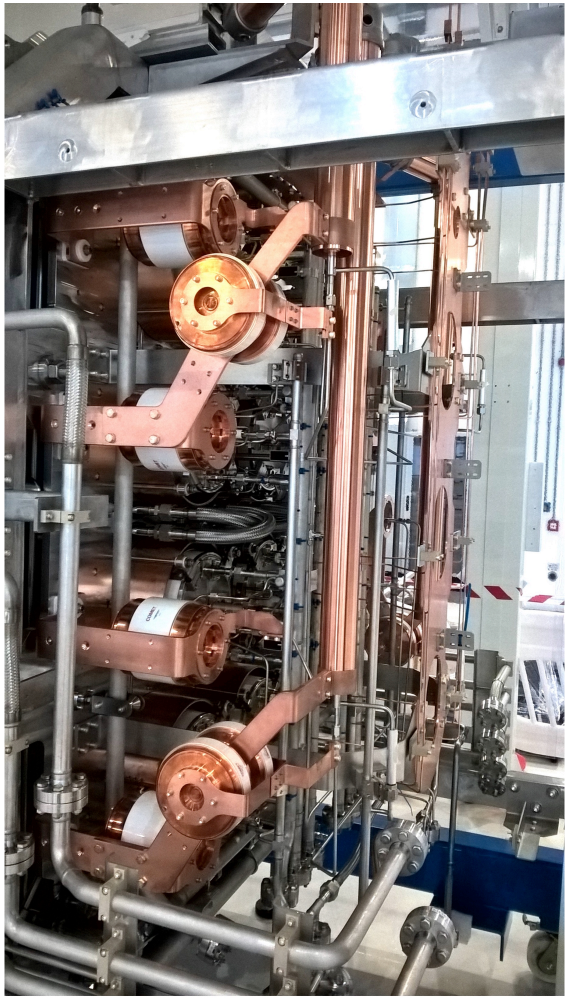


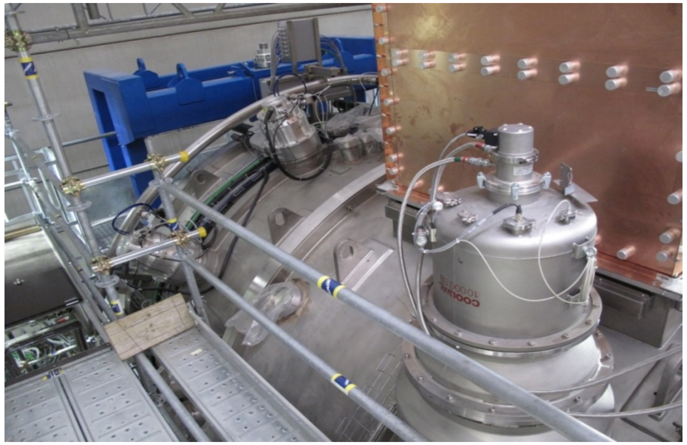
Plasma Source chamber with 8 RF drivers during assembly

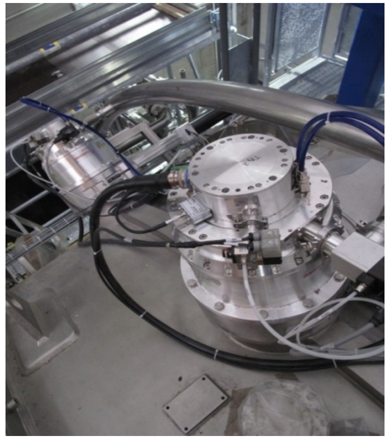


upstream side of 4 RF drivers after assembly

SPIDER auxiliaries







Turbo pumps and cryo pumps installed just outside of the SPIDER Vacuum Vessel

electrical connections and RF capacitors, gas injection and other auxiliaries on the upstream side of the source

Air coolers and cooling towers installed on the roof. Total power dissipated: 17MW

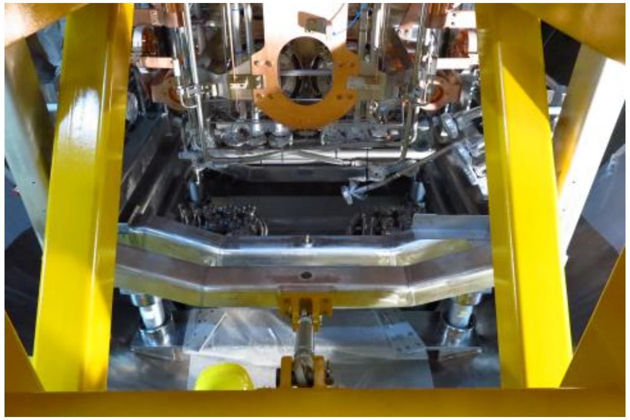
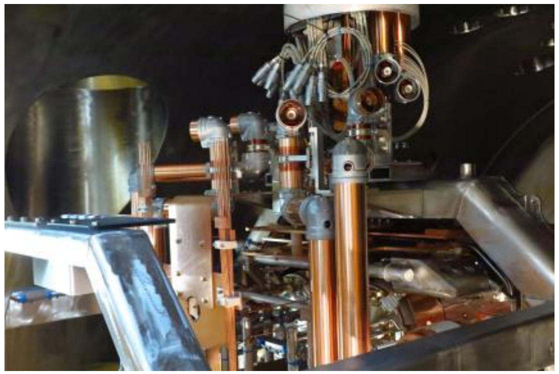
Overview of cooling plant: pumps and heat exchangers

Università degli Studi di Padova

SPIDER beam source installation (Feb. –Mar. 2018)

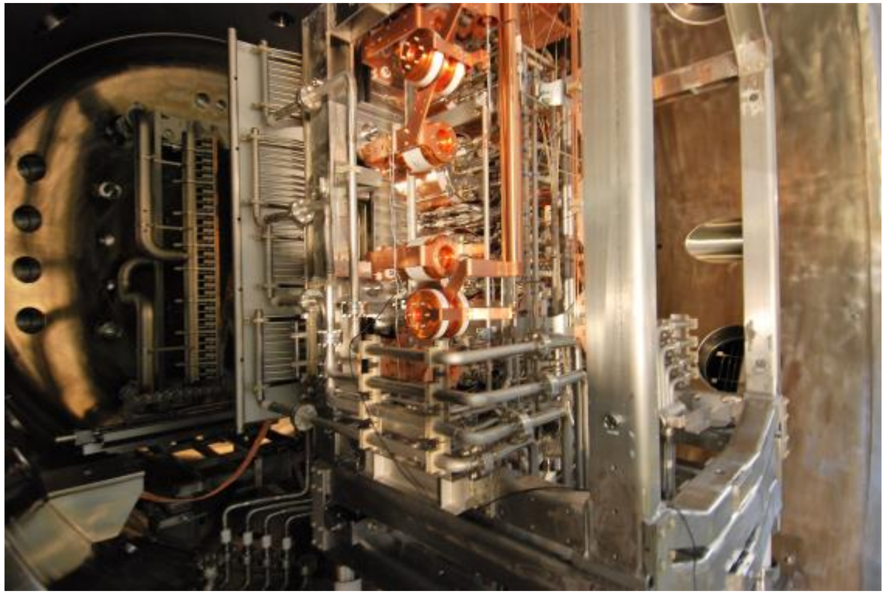
CONSORZIO RFX
Ricerca Formazione Innovazione

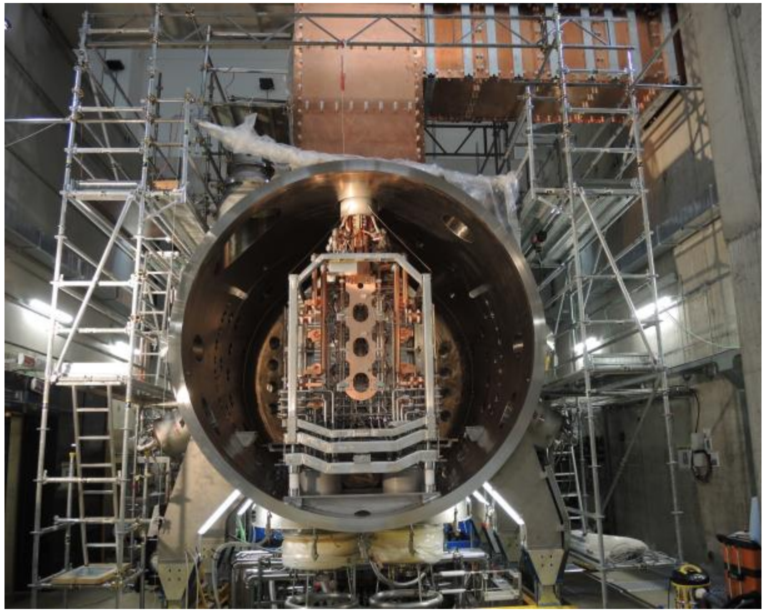



Installation of SPIDER BS inside vacuum vessel

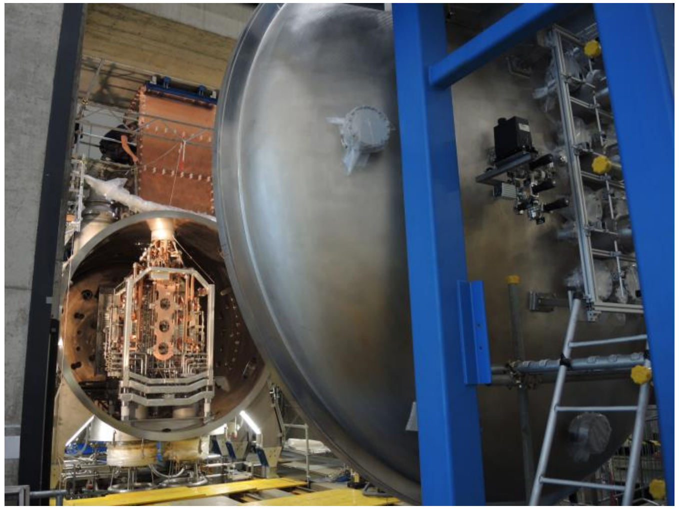
SPIDER beam source installation (Feb. –Mar. 2018)



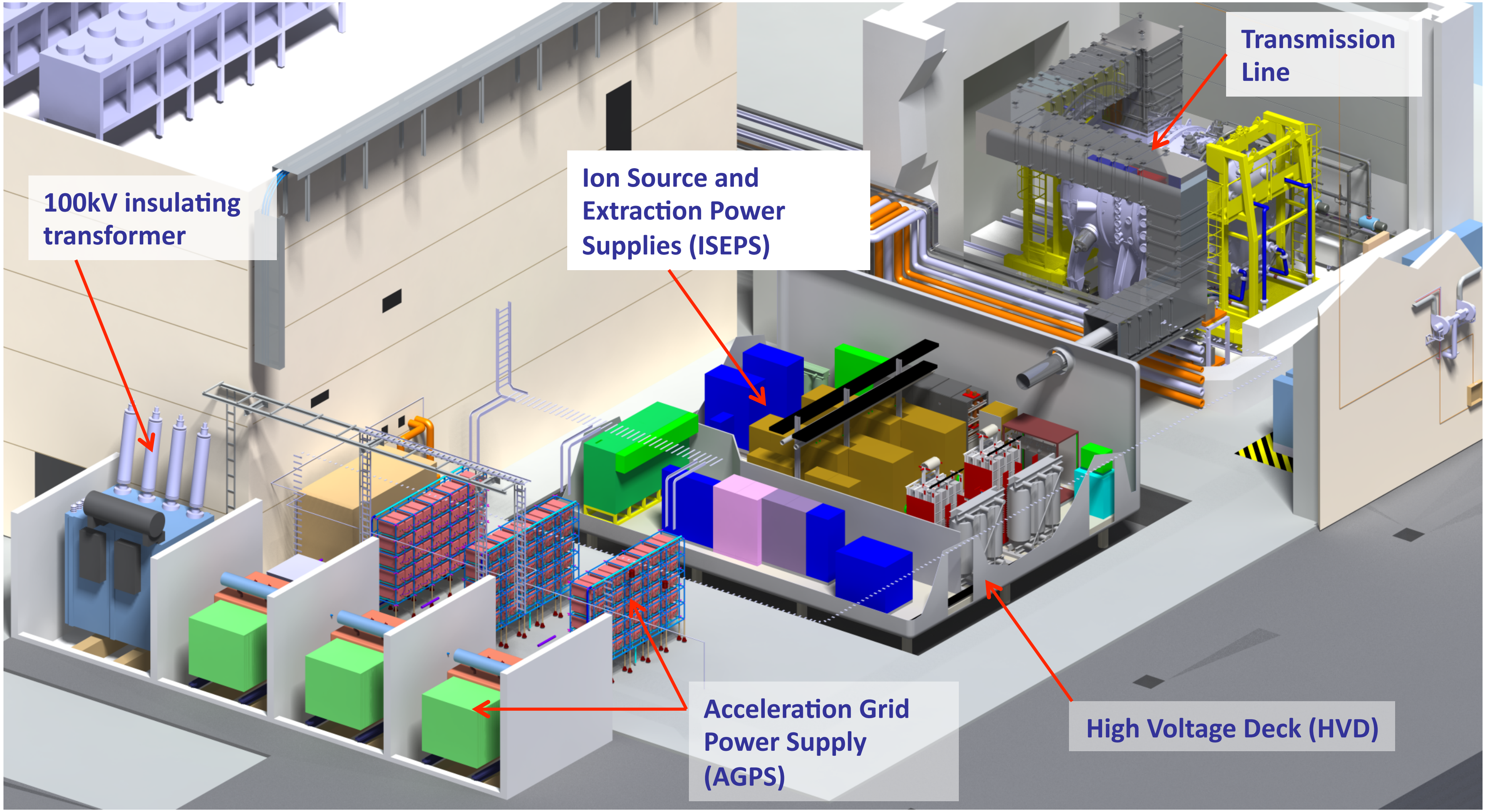


On 8th March all connections have been completed and the vacuum vessel lid closed

Leak test of hydraulic circuits from external flanges have been started



SPIDER Power Supplies



3D CAD view of SPIDER Power Supply, TL and Vessel

SPIDER Ion Source Power Supplies

Supplier: Coelme (I)

Accepted

External view of the HVD

SPIDER TL installed outside the Bio-shield

Supplier: OCEM Power Electronics

Accepted

Ion Source Power Supply inside HVD

All power supply systems procured by F4E have been installed, tested and accepted in 2017

Integration with other plants, i.e. Vacuum vessel, cooling, medium voltage power grid, CODAS and Interlock systems was completed before Feb. 2018

SPIDER Acceleration Grid Power Supplies

Suppliers:
- ECIL (IN)
- Transformers and rectifiers ltd (IN)

Installation completed

Commissioning to be started

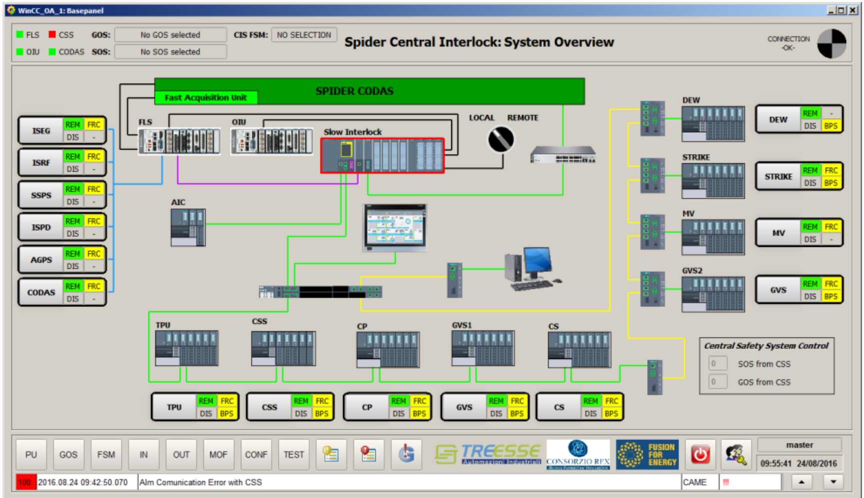
SPIDER AGPS: Dummy Load and PSM's indoor (left side) and multi-winding insulating transformers outdoor (right side)

- Delivery on site of the AGPS components in March 2016
- Installation activities started in July 2016 and completed with troubleshooting in April 2018 (in between there were some long breaks due to administrative issues in the management of the installation contract)
- Insulation test performed in April 2018
- Presently commissioning and power tests are in progress

SPIDER CODAS & Interlock

SPIDER Instrumentation and Control is directly procured by NBTF Team on behalf of F4E

- **CODAS and Interlock plant systems procured and installed**
- **In July 2016 Site Acceptance Tests performed and successfully completed**
- **In Summer 2017 integrated commissioning between control and plant systems was started**



SPIDR Central Interlock - top-level HMI panel

Data center to host both SPIDER and MITICA central servers and data storage

UNIVERSITÀ DEGLI STUDI DI PADOVA

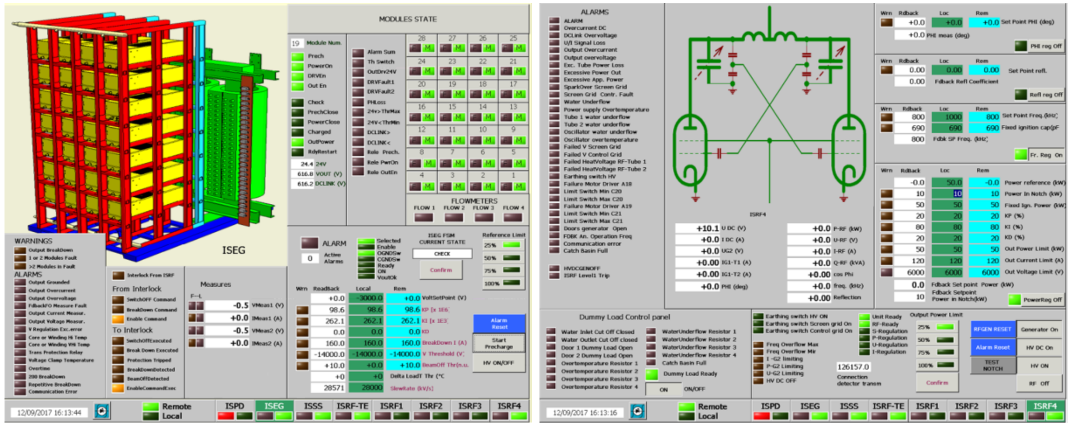
CONSORZIO RFX Ricerca Formazione Innovazione

SPIDER Integrated Commissioning

In 2017 commissioning and power integrated tests with CODAS and Interlock were performed integrating: Ion Source Power Supply (ISEPS), Vacuum and Gas injection System (GVS), some diagnostics

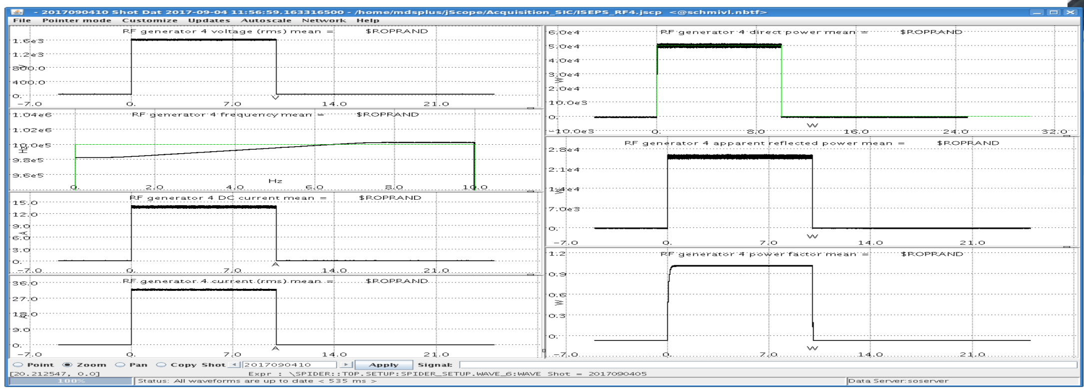
FUSION FOR ENERGY

Integrated commissioning of Cooling plant and AGPS not yet performed



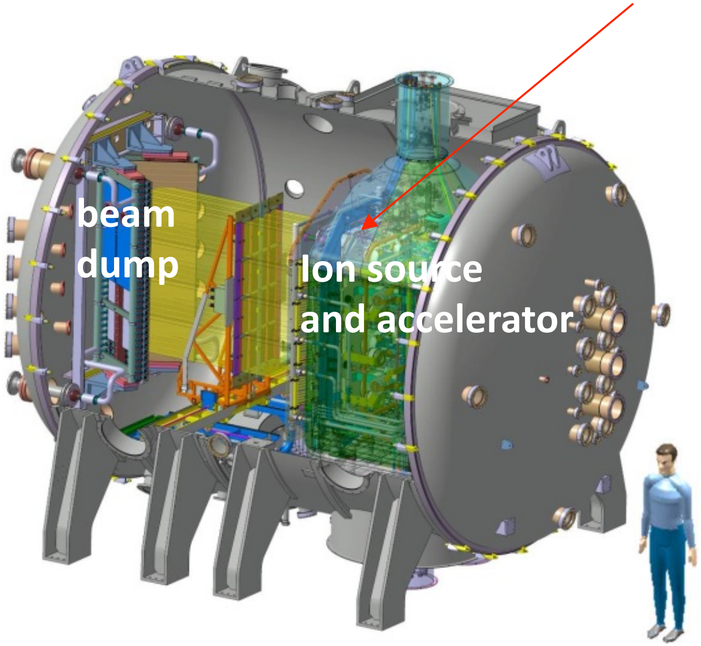
Examples of HMI pages to control SPIDER PS's plant systems

SPIDER commissioning session from the temporary local control room



Signal waveforms acquired during PS's commissioning

SPIDER Source diagnostics

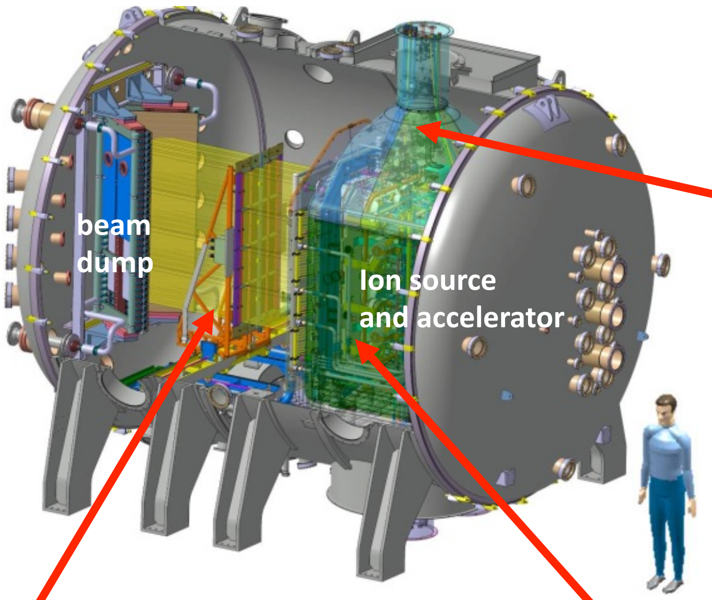


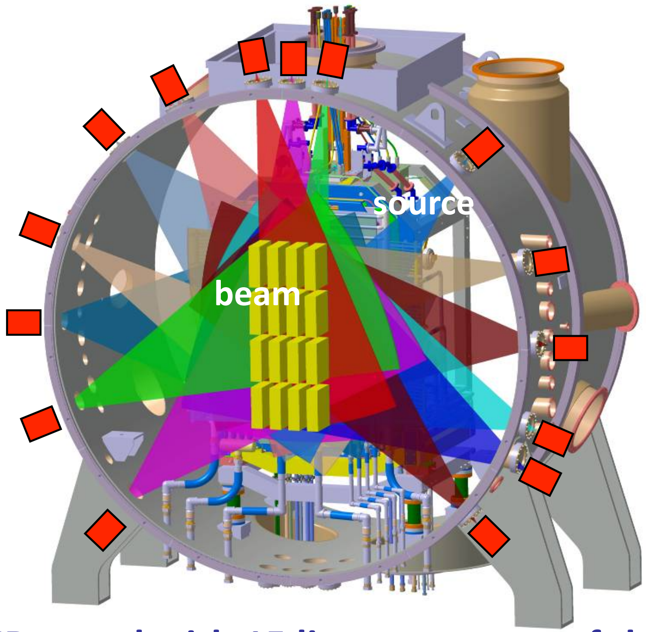
Electrostatic probes
(Plasma uniformity, T_e, n_e,)
Calorimetry and surface thermocouples
(power load on source components)
Electrical currents in Power Supplies and Grounded Grid

Source optical emission spectroscopy
(source plasma T_e, n_e, n_H-, n_{Cs}, n_H, impurities)
Cavity Ring Down Spectroscopy (n_H-) Laser Absorption spectrosocpy (n_{Cs})

- **almost all SPIDER Source diagnostics are installed and operating**

SPIDER Beam diagnostics





view of SPIDER vessel with 15 linear cameras of the tomographic diagnostic with corresponding lines of sight

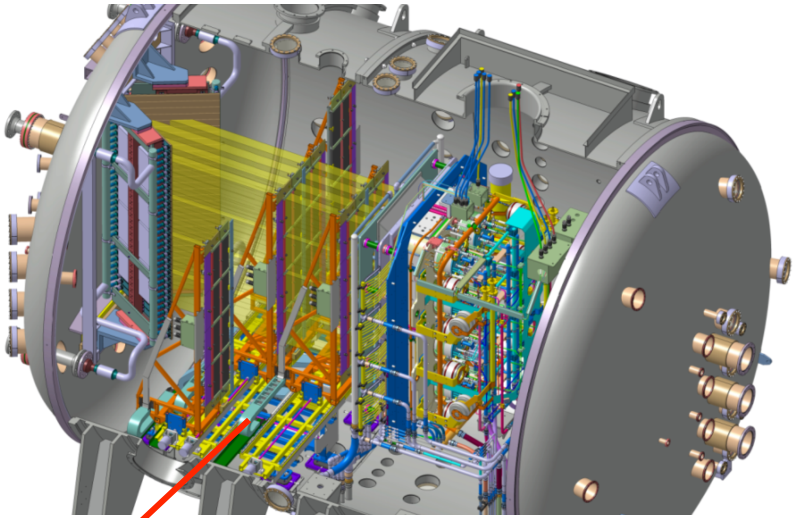
Instrumented calorimeter STRIKE
(beam uniformity over 2D profile, beamlet deflection and divergence, resolution 2mm, < 10 s beam pulse)

Beam emission spectroscopy (beam divergence, stripping losses)
Beam tomography
(beam uniformity over 2D profile, resolution 1/4 beamlet group)
Neutron imaging
(beam uniformity horiz. profile, resolution 30-40 mm, D only)
Calorimetry and surface thermocouples
(beam uniformity vert. profile, resolution:70 mm)

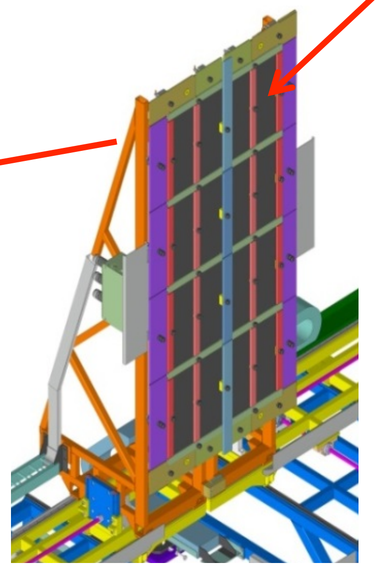
- most of SPIDER Beam diagnostics are already installed

SPIDER STRIKE beam diagnostic

- **High resolution calorimeter based on unidirectional carbon fiber composite (CFC) tiles (transmit heat mainly in one direction)**
- **assembly in progress**



Prototype tile (1 full size) manufactured by Toyo Tanso



CAD model of STRIKE showing the front surface of the target

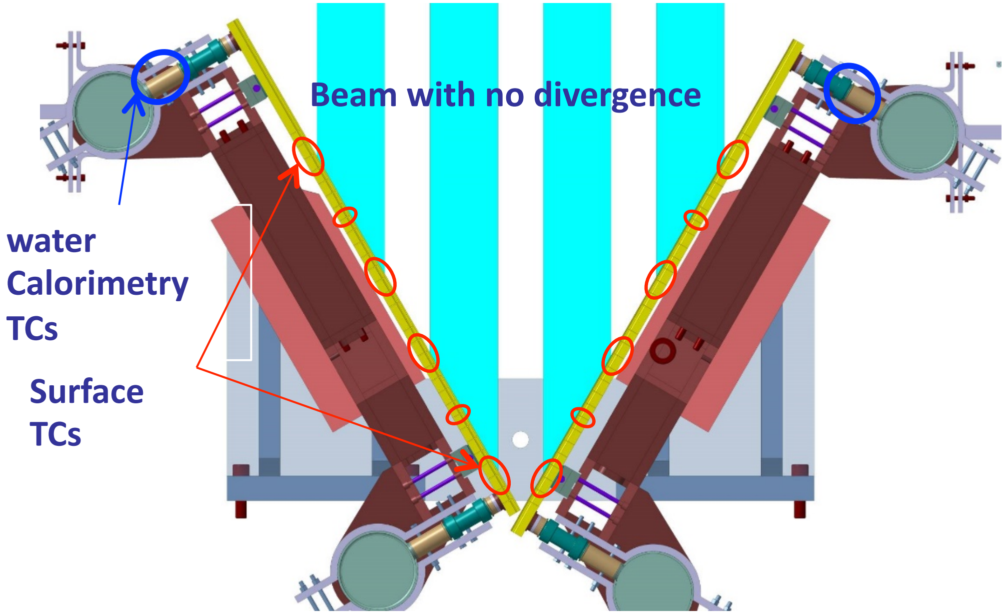
See presentation:

- **P1-17** , A. PIMAZZONI, Thermal characterization of the SPIDER diagnostic calorimeter

SPIDER Beam Dump calorimeter

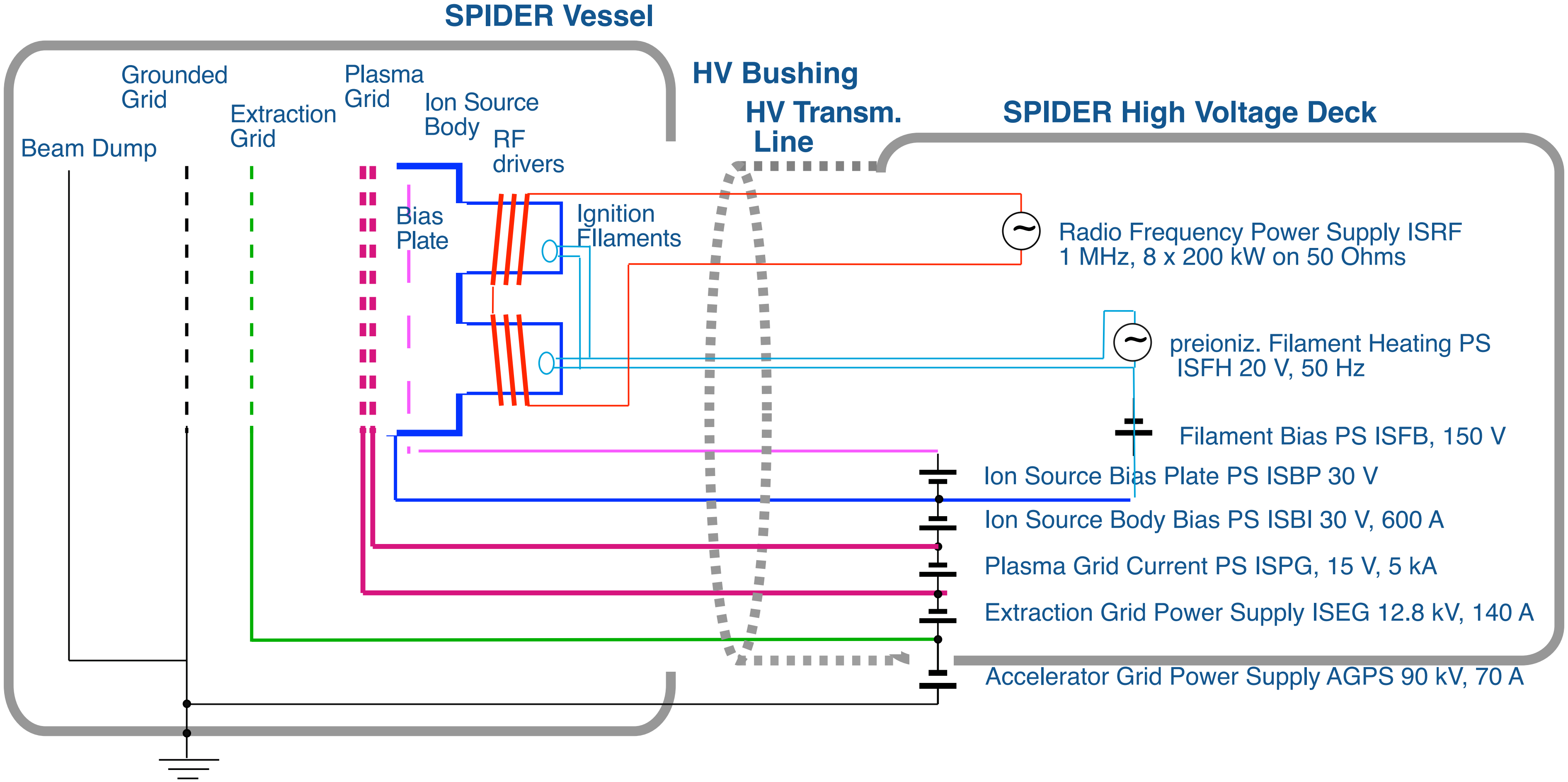
SPIDER Beam Dump: Front side

up to 6 MW beam power in steady state, procured by INDIA Domestic Agency



- Surface calorimetry, water calorimetry thermocouples
- Neutron Imaging, detectors based on Gas Electron Multiplier (GEM) with neutron-proton converter foil

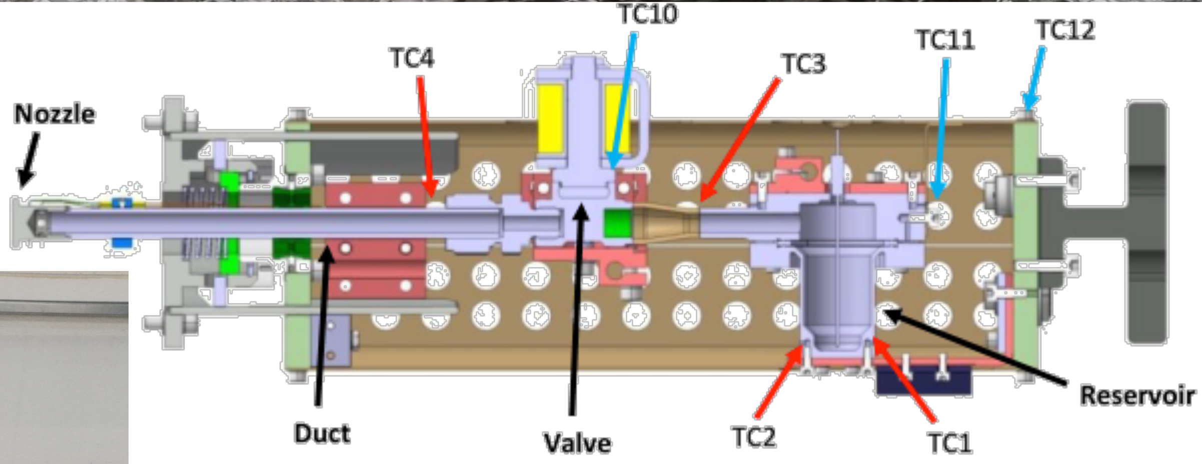
SPIDER power supply schematic



SPIDER caesium oven and CAesium Test Stand (CATS)

Caesium oven prototype tested in 2018

- **thermal design validated**
- **valve operation commissioned**

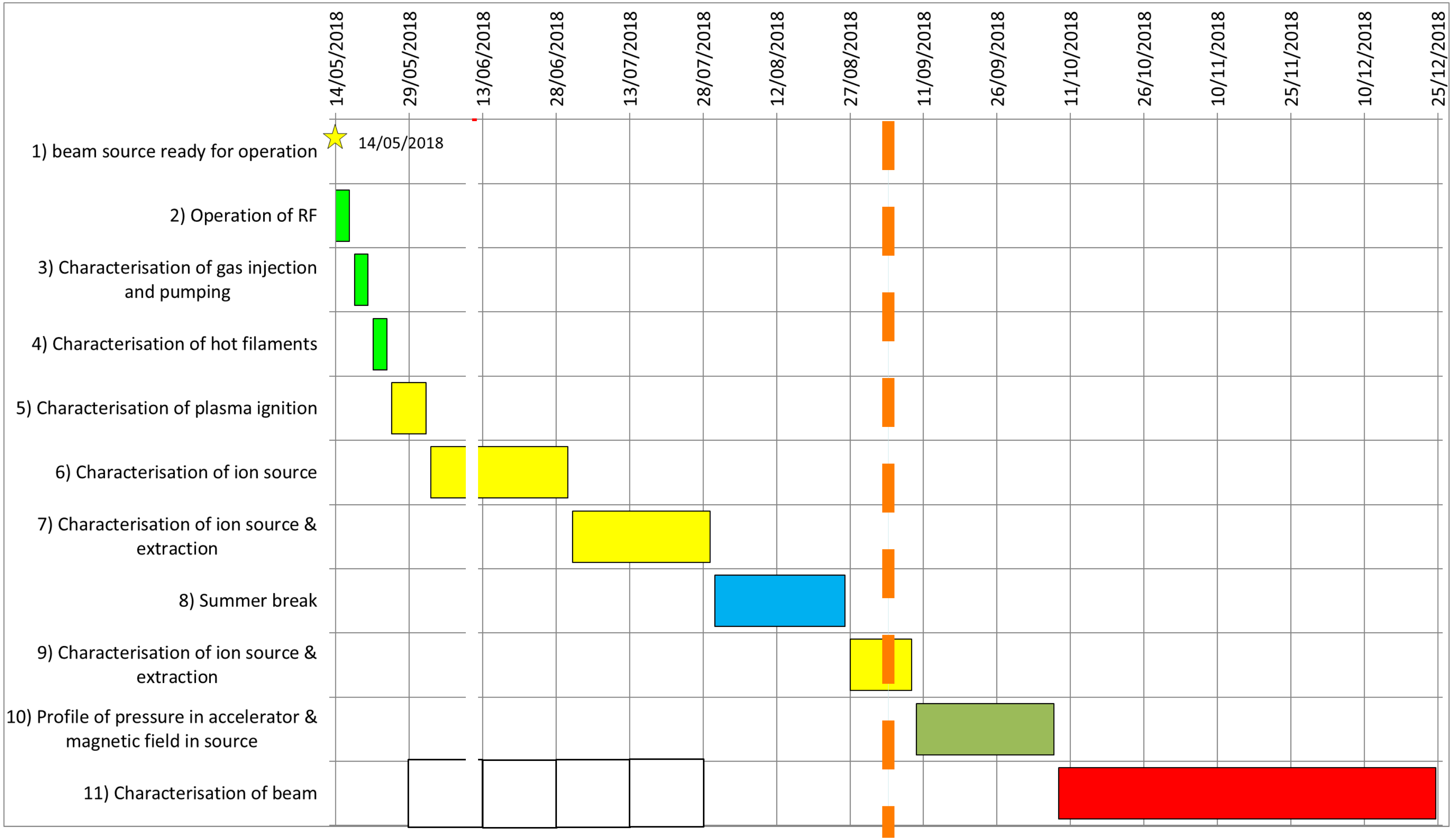


see relevant presentations and posters:

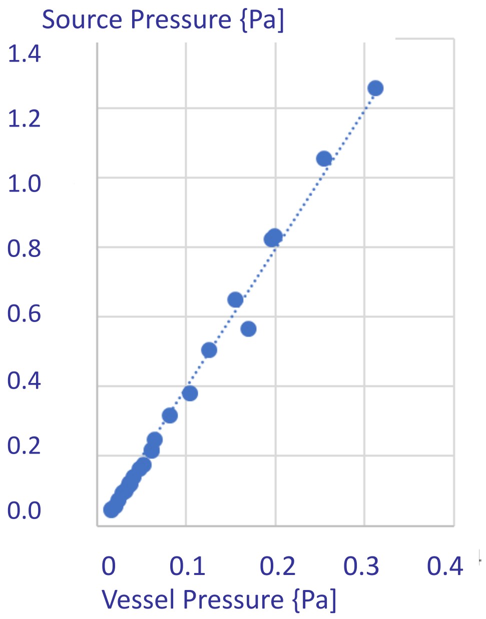
- **WedO2**, E. SARTORI, Study of caesium - wall interaction parameters within a hydrogen plasma
- **FriO5**, M. FADONE, Plasma characterization of a Hall Effect Thruster for a Negative Ion Source concept
- **WedO3**, A. MIMO, Studies of the Cs Dynamics in Large Ion Sources using the CsFlow3D Code
- **P1-18**, E. SARTORI, Diagnostics of Caesium emission from SPIDER caesium oven prototype

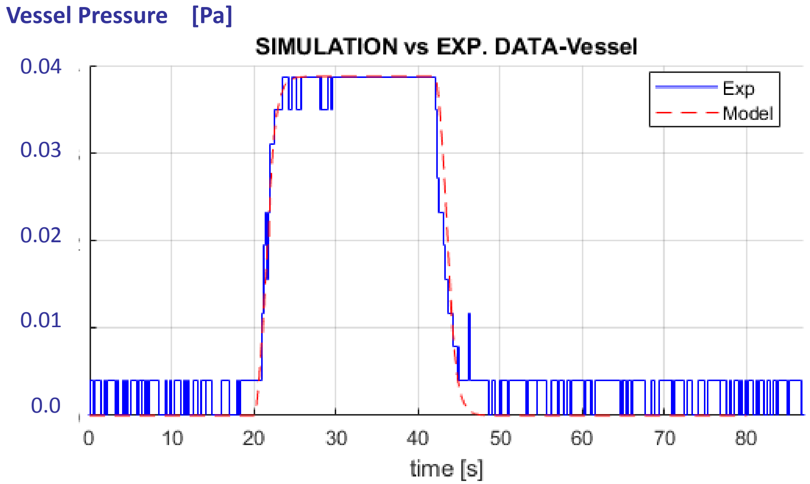
SPIDER experimental plan 2018

the SPIDER experimental phase was officially started on 16th May 201

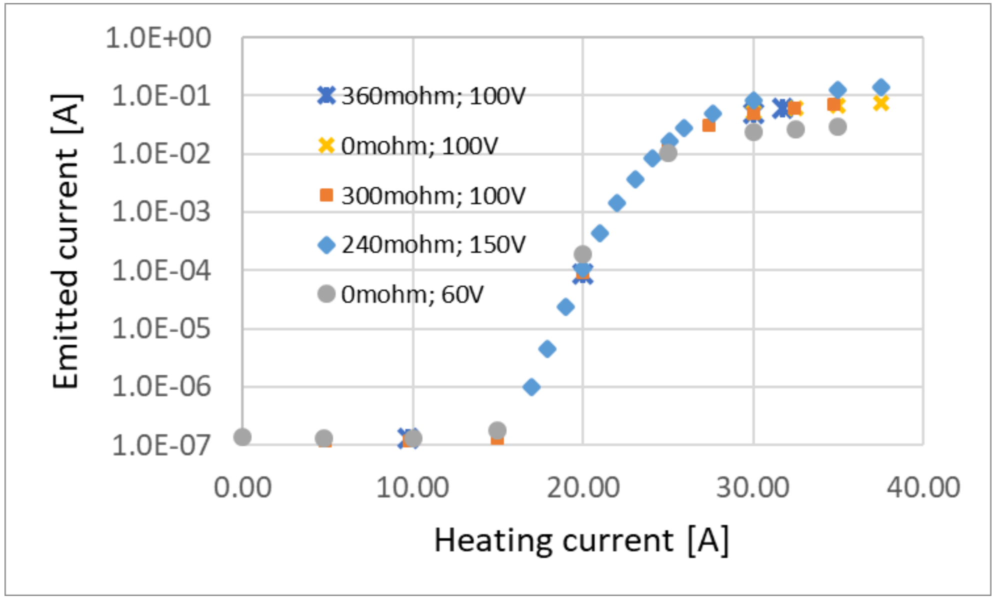


First SPIDER experiments: characterization of vessel pressure vs source pressure





source and vessel pressures measured by capacitive sensors are in fairly good agreement with numerical dynamic models



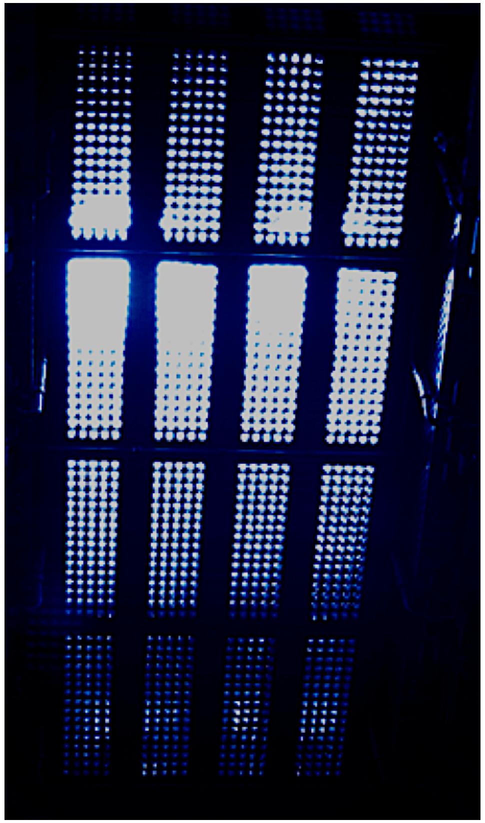
Current emitted by pre-ionisation filaments as a function of the heating current in different conditions

First SPIDER experiments: characterization of the Plasma Source

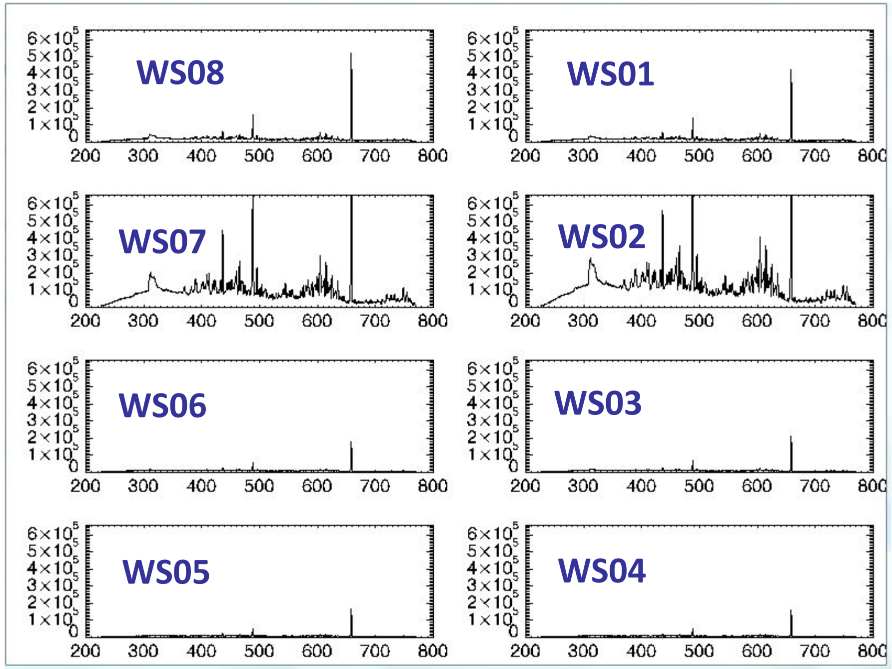
In the very first experimental phase, only one pair of RF drivers (#3 and #4) was connected to a generator (up to 40 kW). In a subsequent phase, also drivers #7 and #8 were used.

Light emission spectroscopy looking axially through the RF drivers recorded an intense signal as soon as the plasma was ignited.

Layout of 8 RF drivers



Plasma light seen from downstream side



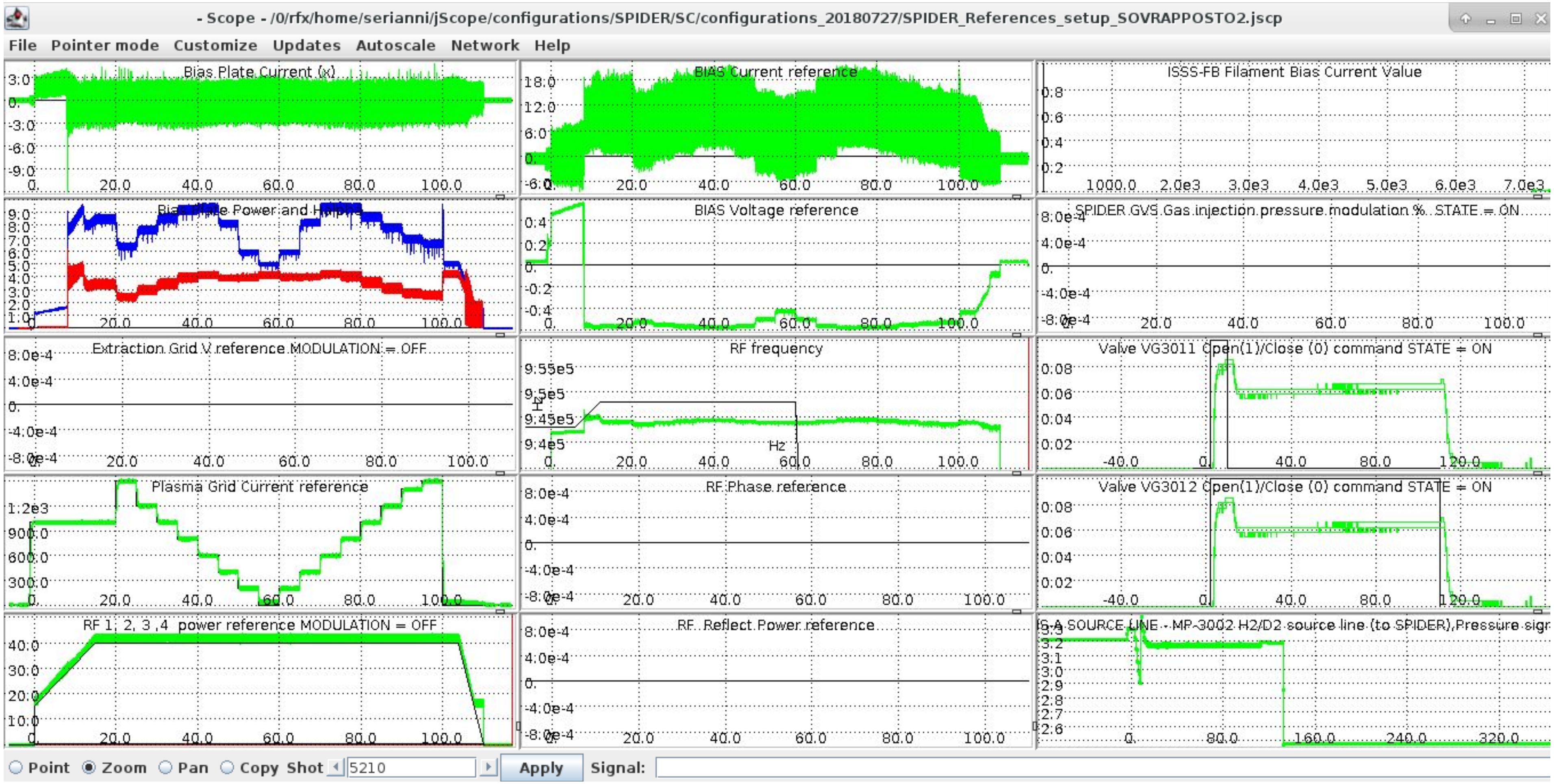
Plasma light spectra measured through the RF drivers, only drivers #3 and #4 are powered

example of SPIDER pulse (2018060807)

UNIVERSITÀ DEGLI STUDI DI PADOVA

CONSORZIO RFX Ricerca Formazione Innovazione

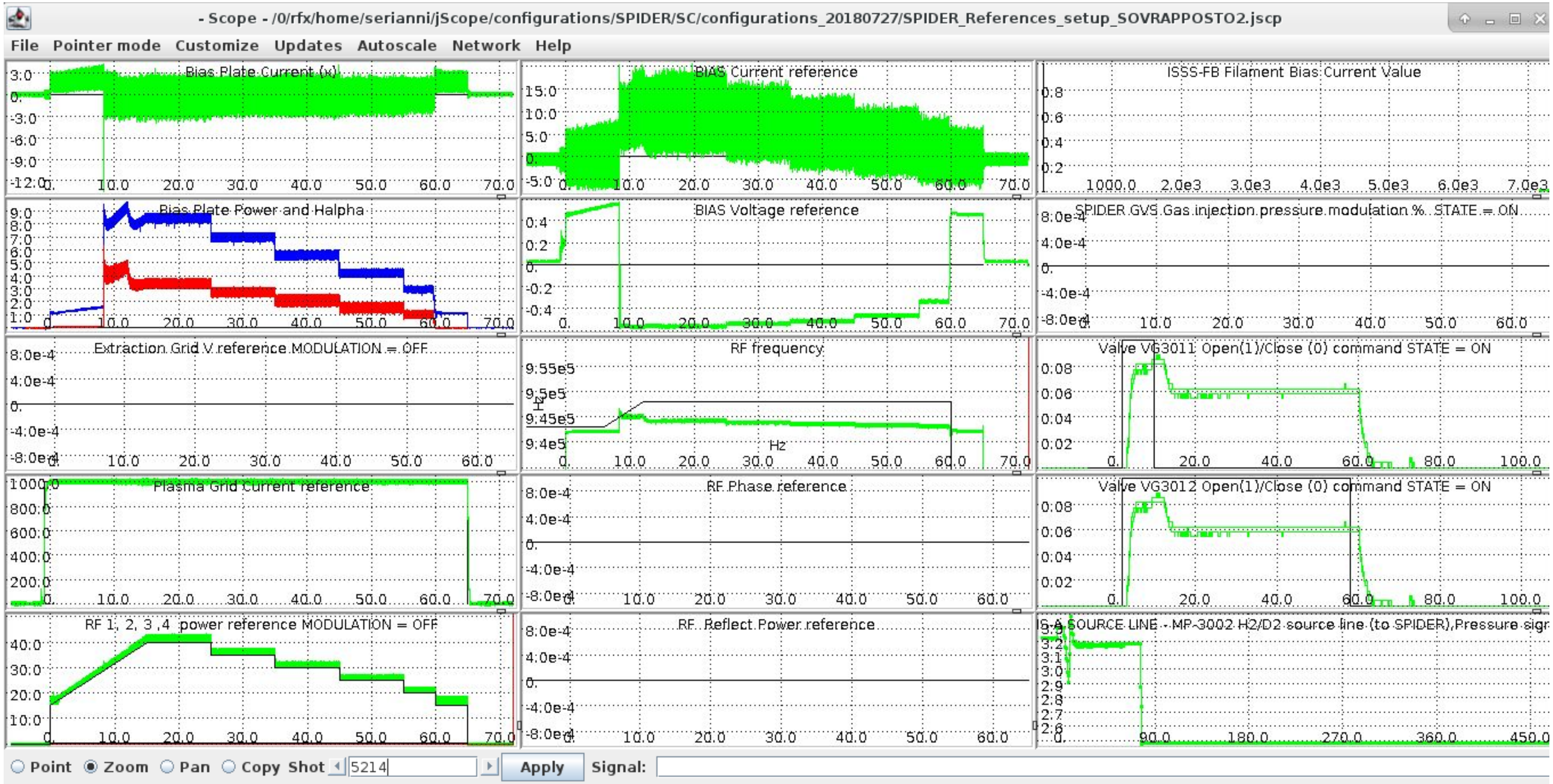
Characterisation of source plasma vs filter field in a single pulse



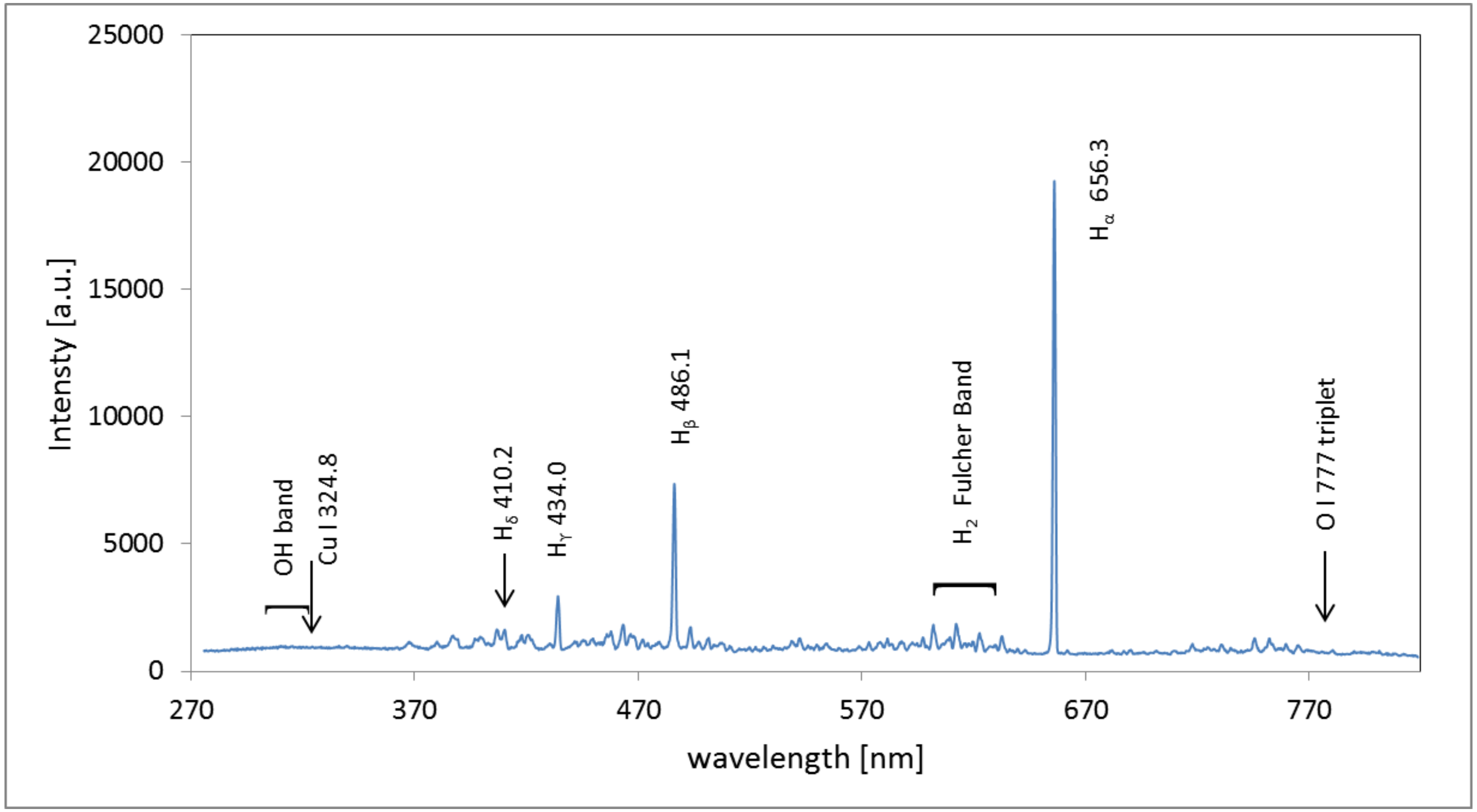
UNIVERSITÀ DEGLI STUDI DI PADOVA

Characterisation of source plasma vs RF power in a single pulse

CONSORZIO RFX
Ricerca Formazione Innovazione



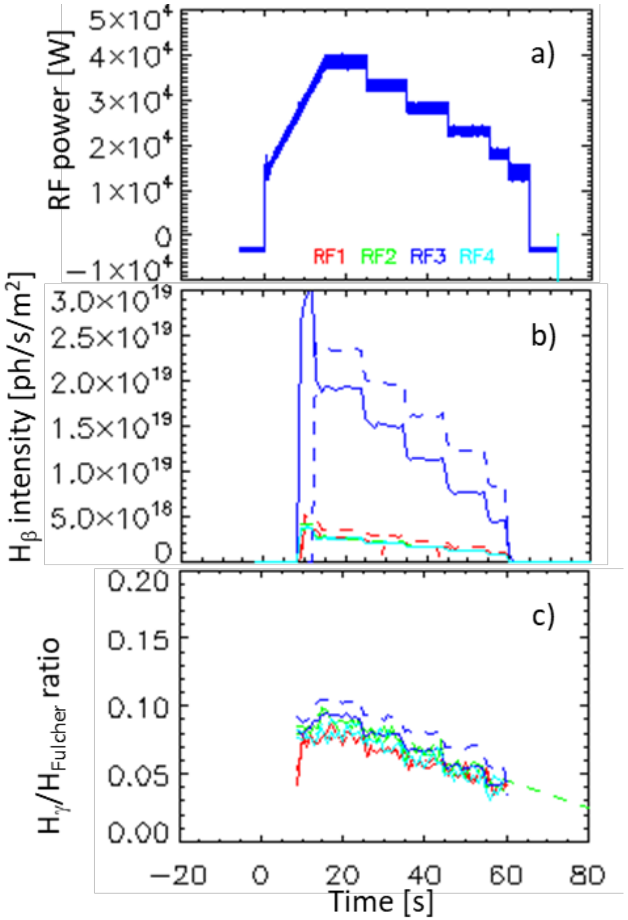
First SPIDER experiments: characterization of the Plasma Source plasma light spectra



typical spectrum of the plasma light from the SPIDER Source, after several weeks of operation (pulse #5210). No visible traces of OH, Cu or O emission.

At the beginning of SPIDER operations a strong OH emission was visible.
Sometimes also Cu lines during arcs on the back of the source

First SPIDER experiments: characterization of the Plasma Source effects of RF power



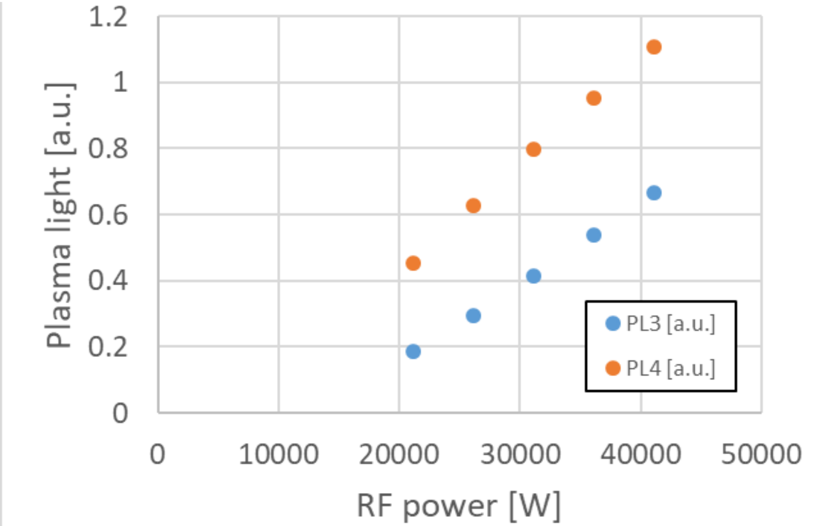
time history of pulse #5214.

The light emitted by the plasma in the active drivers (#3 and #4) is linearly dependent on RF power. A similar trend is generally found in the Hβ line intensity.

Assuming that the plasma light is correlated with the electron density, this indicates a linear dependence of electron density on RF power, as found in numerical models.

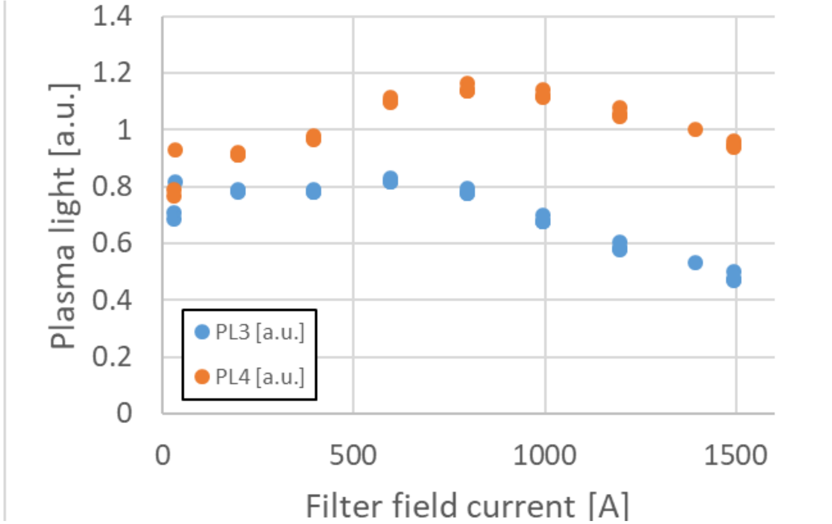
The ratio between the intensities of Hβ line and Fulcher band also depends on the RF power, hinting at a dependence of the dissociation degree on the RF power.

First SPIDER experiments:
characterization of the Source plasma
effects of magnetic filter field and asymmetry



Plasma light from drivers #3 and #4 as a function of the RF power.

- **asymmetry (2x) between the plasma light in the two drivers**
- **similar asymmetry also on the spectrum lines**
- **plasma light is very reproducible with clear dependence on the filter field current**



Plasma light from drivers #3 and #4 as a function of the filter field current.

- **the emitted light reaches a maximum for 600-700A;**
- **emission is not symmetrical and the asymmetry increases with current.**
- **The Hβ line intensities exhibit almost similar dependence**

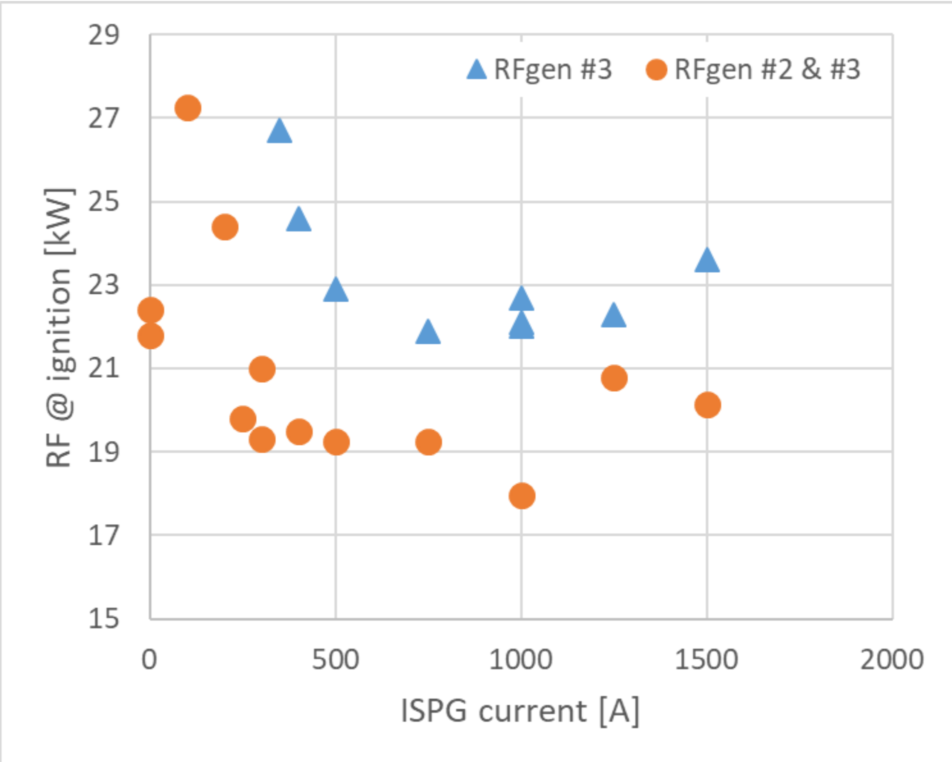
=> plasma drift near the drivers, deserving further investigations.

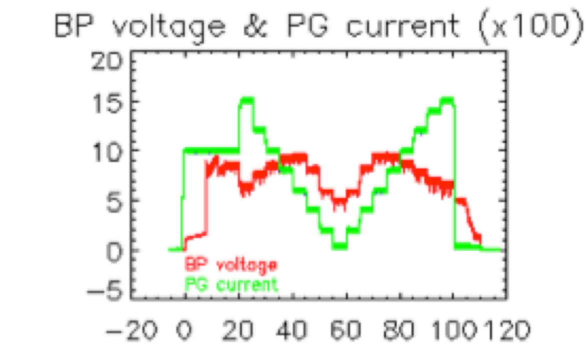
First SPIDER experiments: characterization of Source plasma

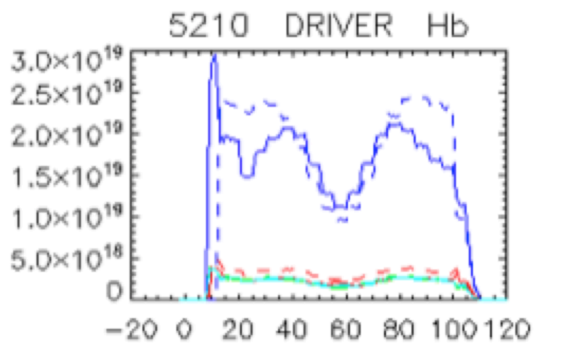
Università degli Studi di Padova

Consorzio RFX
Ricerca Formazione Innovazione

plasma ignition conditions







- **Plasma ignition conditions depend on gas pressure, on magnetic filter field (PG current) and also on the position of the RF driver used**

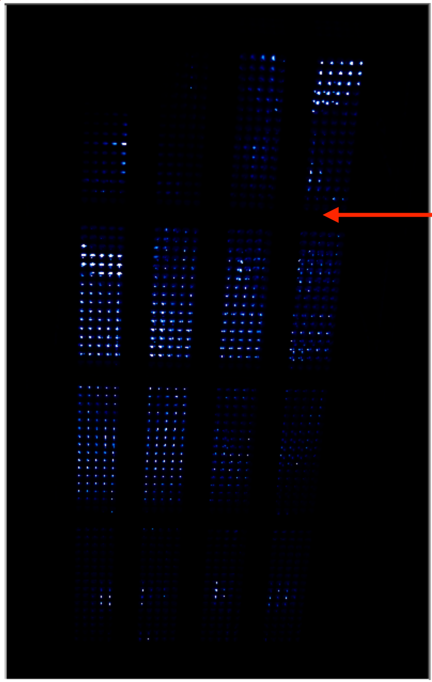
Source pressure: 0.3Pa
Vessel pressure: 0.075Pa

- **electrical breakdowns between auxiliaries on the rear side of the plasma source often occur before or during plasma ignition**

Università degli Studi di Padova

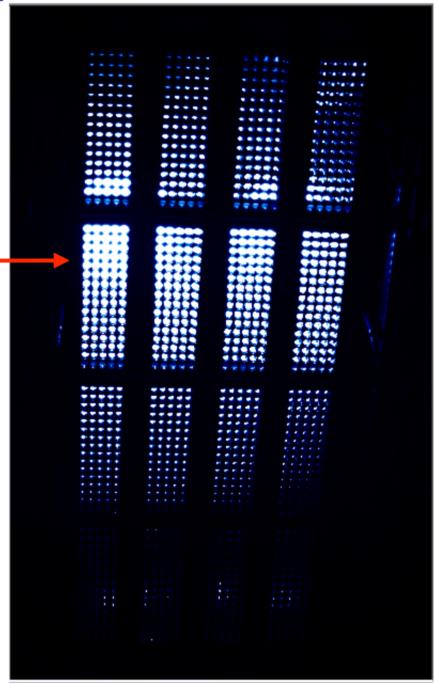
Visualisation of plasma through grounded grid

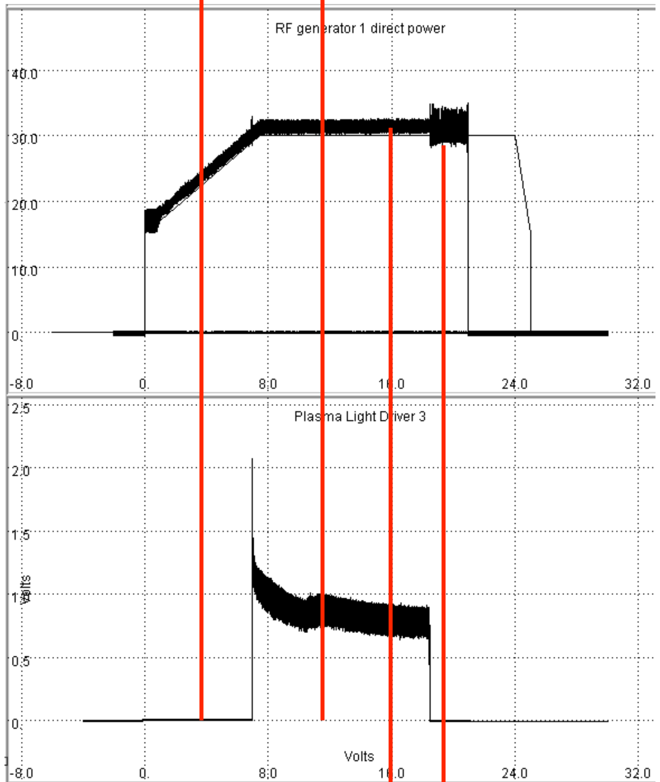
CONSORZIO RFX
Ricerca Formazione Innovazione

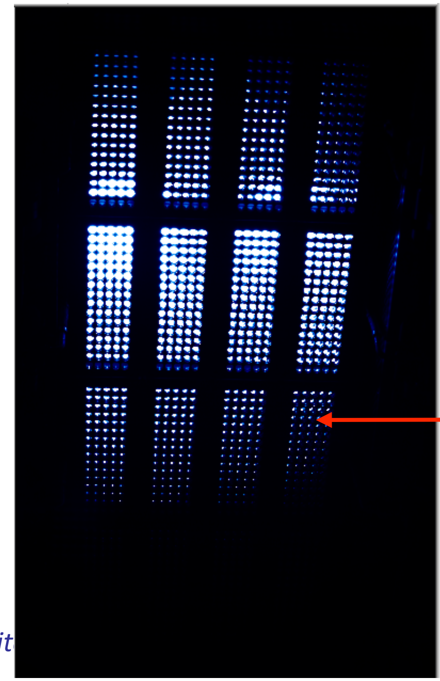


filaments only

filaments and plasma







plasma only

electrical breakdown on rear side of plasma source

iter
china eu india japan korea russia usa

FUSION FOR ENERGY

ITER JADA

ITER-India

CONSORZIO RFX
Ricerca Formazione Innovazione

ENEA

INFN

Università degli Studi di Padova

Max-Planck-Institut für Plasmaphysik
EURATOM Association

KIT
Karlsruhe Institute of Technology

CCFE
CULHAM CENTRE FUSION ENERGY

Università degli Studi di Milano Bicocca

Istituto di Fisica del Plasma "Piero Caldirola"
Consiglio Nazionale delle Ricerche

ICMATE

CNR NANOTEC
INSTITUTE OF NANOTECHNOLOGY

INFN Laboratori Nazionali di Legnaro

Conclusions

we have just got a new bike,

now we have to push the pedals very hard...

... and many thanks for the opportunity of meeting you in Novosibirsk!